Device for preventing the displacement of an optical elementDEVICE FOR PREVENTING THE DISPLACEMENT OF AN OPTICAL ELEMENT

Cross Reference to Related Applications

[001]   This is a U.S. National Phase entry under 35 U.S.C. § 371 of International Application No. PCT/EP2004/009326 filed August 20, 2004 which designated the U.S. and at least one other country in addition to the U.S. and which claimed priority to German Patent Application No. 103 39 362.5 filed August 27, 2003.

Background of the Invention

[002]   The invention relates to a device for preventing the creeping of an optical element, in particular a lens or a mirror, the optical element being connected to a mount via connecting members arranged on the circumference of the optical element, and the position of the optical element in an objective deviating from the vertical axial position.

[003]   To date, in semiconductor lithography, optical elements have been held in a mount by means of various clamping techniques, clamping in combination with self-closure and via bonded connections, for example by gluing. It is generally known that in the case of screwed connections it is necessary to shape the screws so as to keep the elasticity of the screw shank as low as possible in order to keep within a tolerable range the loss of prestressing force owing to setting and relaxation effects of the shaft. Elements of high elasticity are used with clamped connections or

mechanical coupling points in order to thus minimize
the effects of tolerances during installation, and to
minimize temporal changes acting during operation on
the parts that determine functioning.

[004]   It is also known from the older DE 102 11 791.8
that in conjunction with a vertical optical axis the
optical element is glued onto elastic connecting
members or spring elements. Before the optical element
is glued in, it is laid onto the elastic connecting
members, and the optical axis of the optical element is
aligned parallel to the mount axis. In this case,
gravity acts approximately along the optical axis of
the optical element. The optical element can then be
connected or glued to the elastic connecting members.

[005]   It is possible for a mount to be arranged in
projection objectives together with the optical element
such that the optical axis of the optical element is
horizontal or is inclined at a specific angle to the
vertical. As a result, gravity acts not only along the
optical axis of the optical element, but also
transverse thereto. Because of the bearing of the
optical element on the elastic connecting members, the
effect of gravity acting transverse to the optical axis
is generally a displacement of the optical axis of the
optical element transverse to the mount axis and,
possibly, a tilting of the optical axis of the optical
element in relation to the mount axis. The elastic
connecting members are deformed by the weight force,
acting transverse to the optical axis, of the optical
element in such a way that the optical element is
displaced in the lateral direction in relation to its
original position and is tilted.

[006]   A lateral displacement of the optical element
can be corrected during installation in the projection

objective by means of an appropriate displacement of
the mount, no tilting correction being possible by
displacing the mount during installation of the
objective. As is known, for example, from Stuart. T-

5   Smith: Flexures; Gordon and Breach Science Publishers,
2000, it is possible to use the customary methods of
elasticity theory in order to shape and design the
elastic connecting members such that they lead not to a
tilting of the optical element, but only to a lateral

10   displacement in the event of loading by the force of
gravity on the optical element transverse to the
optical axis. The position of the centroid of the
optical element plays an important role in the design
of the elastic connecting members to counteract tilting

15   of the optical element. The sectional loads, resulting
in the event of lateral offset of the optical element
without tilting, of the elastic connecting members
between connecting members and optical element should,
when combined as resulting force, form a force through

20   the centroid of the optical element that is of the same
magnitude as gravity and acts against it. Since,
however, the elasticity of the connecting members can
fluctuate owing to manufacturing tolerances, a
displacement of the resulting force, and thus an

25   impossibly large tilting of the optical element can
occur despite a theoretically correct design of the
connecting members counter to tilting. The
abovementioned correction of the lateral offset is,
however, possible only when the offset does not change

30   with time. In a preferred fastening of the optical
element by means of gluing, however, it is possible for
the glue to creep as a consequence of shear stresses,
and thus, again, for there to be a temporally variable
lateral offset.

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[007]   It is likewise known from the older DE 102 11
791.8 for there to be inserted between the elastic

connecting members and the optical element inserts such
as, for example, angles or wedges, that provide
additional gluing points between the optical element
and the connecting members via suitable connections.
5   Even by thus lowering the glue stress and raising the
stability, the load changes caused by relaxation,
setting and creep phenomena of the optical element at
the connecting points cannot fundamentally be reduced.
The inserts only put off the problem. Likewise, no
10   glues free from creep are yet known.

[008]   Lateral bearings for the optical element via
two "half" bearings are likewise known from Paul R.
Yoder: Design and Mounting of Precision and Small
15   Mirrors in Optical Instruments, Spie Volume TT32, page
154. With any type of fastening, for example screwing
an optical element on or gluing it, large local defects
arise here in the region of the fastening points of the
optical element. However, as is known from US
20   4,733,945, a simple mounting technique is not possible
by spherization.

[009]   It is likewise known from investigations
relating to lateral bearing of large mirrors to permit
25   the lateral bearings to act tangentially or at a
specific angle to the tangent, and thereby to minimize
the bending of the optical element as far as possible.
Such investigations are described in the Journal of
modern Optics, 1988, by Schwesinger, G.: Lateral
30   support of very large telescope mirrors by edge forces
only. If the tangential bearings are glued onto the
optical element, the lens likewise creeps through being
acted upon by gravity.

35   [0010] Fastening the optical element by soldering, as
is known from DE 197 35 760 A1, produces no
advantageous improvement, since the optical element is

distorted or warped when experiencing thermal
expansion. Fastening by clamping produces local
stresses and requires a larger optically unused
overflow of the optical element.

[0011] Again, active bearings known, for example, from
DE 100 51 706 A1, such as readjusting the creeping
movement of the optical element with the aid of an XY
manipulator and/or a tilt manipulator constitute only
unsatisfactory solutions. It is true that the rigid
body movement would be compensated in the case of such
solutions, but not so the deformations, produced by
stress redistribution at the gluing points, of the
optical element. Moreover, such bearings require a
complicated design that entails high costs and requires
electronic control.

[0012] Reference may be made to Hale, L. et al.: New
photolithography stepping machine, Lawrence Livermore
National Laboratory, 1995, UCRL-ID-120313, page 4 ff.
and page 25 for the further prior art.

[0013] It is therefore an object of the invention to
provide a device for preventing creeping of optical
elements arranged and glued in mounts, optical axes of
the optical elements not being vertical.

Brief Summary of the Invention

[0014] The object is achieved according to the
invention by virtue of the fact that in order to
compensate the dead weight at least of the optical
element at least one holding element is provided, at
least one holding element advantageously being designed
as a soft spring element, via which the optical element
is held on a housing part of the objective.

[0015] The optical element that is connected by gluing
to a mount via connecting members has at least one
holding element for dead weight compensation or for
compensating the tilting error. Creeping can now be
5   prevented by virtue of the fact that the dead weight of
the optical element is absorbed by the at least one
holding element, which can be designed as a soft,
prestressed spring element. The prestressing force of
the spring element should correspond in this case to
10   the weight force of the optical element. It is possible
with the aid of such a device for the gluing points
between the connecting members and the optical element
to be virtually unstressed with regard to the shear
stress that triggers creeping.

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[0016] In an advantageous refinement of the invention,
it is provided that the at least one holding element is
designed as a pneumatic spring element that is
connected to the optical element.

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[0017] According to the invention, the holding element
can also be designed as a pneumatic spring element, and
this permits a very simple variation of the spring
stiffness of the spring element by means of a gas
25   accumulator located at another point. It can also be
provided here that the supporting forces can be
distributed, and that the deformation of the optical
element as a consequence of spring forces is thereby
minimized.

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[0018] In a refinement of the invention according to
the invention, it is further provided that the action
line of the resulting force of the spring elements can
be displaced by an adjusting mechanism to the centroid
35   of the optical element.

[0019] When use is made of an adjusting mechanism with
the aid of which the action line of the resulting force
from the spring elements or weight compensation spring
elements can be displaced, the action line can be
5   displaced in such a way that a torque opposing the
tilting can be transmitted about the centroid of the
optical element in order thus to compensate an
impossibly large tilting of the optical element.

10   [0020] Exemplary embodiments of the invention are
explained below in more detail with the aid of the
drawings, in which:

Brief Description of the Drawings
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[0021] figure 1   shows a schematic of the
device according to the invention in conjunction with
an optical element;

20   [0022] figure 2   shows a schematic of a
possibility for configuring the device according to the
invention;

[0023] figure 3   shows a schematic
25   illustration of a further alternative possibility for
configuring the device;

[0024] figures   4a and 4b show an illustration of a
possible variant4a and 4b   of the fitting of
30   holding elements to the optical element, and of the
force distribution; and

[0025] figures 5a and 5b   show a schematic of
an adjusting mechanism5a and 5b   for displacing
35   the action line of the resulting force of the holding
elements, the plan view being illustrated in figure 5a,
and the side view in figure 5b.

Detailed Description of Preferred Embodiments

[0026] Figure 1 shows a device 1 in a projection
5   objective PL, illustrated schematically and in part,
for semiconductor lithography, the device 1 being
illustrated in conjunction with an optical element 2,
in particular a lens or a mirror. The optical element
2, whose position deviates from a vertical axial
10 position, is connected to a mount 3 via connecting
members 4 arranged on the circumference of the optical
element 2. The optical element 2 is connected to the
connecting members 4 via cement 5. The optical element
2 is borne as given the presence of a vertical optical
15 axis, forces in the direction of an optical axis 6 of
the optical element 2 being absorbed, as previously.
The device 1 has holding elements 7 that are connected
in each case tangentially to the optical element 2 at
their opposite end points.

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[0027] Because of the illustration in side view, only
one holding element 7 is shown in figure 1, the second
holding element 7 being covered by the first holding
element 7. The holding elements 7 are designed as soft
25 prestressed spring elements. The prestressing of the
spring elements 7 corresponds in this case to the dead
weight of the optical element 2. This produces a
bearing that is insensitive to small displacements of
the fastening points of the spring element 7 on the
30 optical element 2. The fastening points (end points) or
the gluing points 5 are virtually unstressed with
regard to the shear stress that triggers creeping,
because the spring elements 7 compensate the dead
weight of the optical element 2. If the fastening point
35 for the soft spring element 7 is glued on the optical
element 2, creeping is not dangerous here, since this
would change the prestressing force of the spring

element 7 only insubstantially. Since the soft spring
elements 7 absorb the weight of the optical element 2,
something which gives rise to geometric variations in
the course of time during the use of the projection
5   objective PL such as, for example, setting or creeping,
owing to their softness, however, these cause no
changes in load at the optical element 2 that can cause
deformations or rigid body movements.

10   [0028] The action of force, the direction of force and
the magnitude force of the spring elements 7 can be
optimized such that the influence on the lens or mirror
deformation is very slight. Such solutions are already
known from the prior art and can, for example, be taken
15   from the theory of Schwesinger, G. (1954): Optical
Effect of Flexure in Vertically Mounted Precision
Mirrors, f. Opt. Soc. Am 44:417. Furthermore, the
adjustment of the forces in magnitude and direction can
be performed by control elements 8 such as, for
20   example,   adjusting   screws,   piezoelectric,
electromagnetic   or   pneumatic   drives.   These   serve
adjusting purposes in setting the deformation of the
optical element 2. The weight force is illustrated in
figure 1 by an arrow with the reference symbol F_G.

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[0029] Figure 2 shows a further design refinement of
the device 1, only one holding element 7, which is
likewise designed as a spring element, being provided
in this refinement. The spring element 7 is connected
30   to the optical element 2 in this case with the aid of a
connecting element 9 via fastening elements 10 that,
just like the spring elements 7 in accordance with
figure 1, act tangentially at opposite sides on the
optical element 2. When the optical axis 6 runs in a
35   horizontal   direction,   this   means   that   the   spring
element 7 or fastening elements 10 act laterally in the
horizontal plane. The fastening elements 10 can be

designed as strips, wires or cables that can, in turn,
be glued or else screwed onto the optical element 2.
The action line through the centroid of the optical
element 2 is illustrated in figure 2 on the side next
5   to the illustration of the device 1. It is thereby
possible here, as well, to prevent creeping of the
optical element 2 by virtue of the fact that the dead
weight of the optical element 2 is absorbed by the
fastening elements 10 and the soft spring element 7.
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[0030] A further alternative possibility for the
device 1 is illustrated in figure 3. In use here as
holding elements are pneumatic spring elements 11 that
introduce a force into the optical element 2 in the
15 direction indicated by arrows. The pneumatic spring
elements 11 act on opposite sides of the optical
element 2 and each have a piston element that acts on
the optical element 2. The pneumatic spring elements 11
have the same pressure, the spring elements 11 being
20 connected to a gas container 12 that provides a
constant pressure. It is important here that the
pressure is to be selected or can be selected or set
such that the dead weight of the optical element 2 is
compensated. The gas container 12 renders it possible
25 to vary the spring stiffness of the spring elements 11
easily. The action line through the centroid of the
optical element 2 is likewise specified to the side of
the device 1 in figure 3. In the case of a pneumatic
solution, the supporting forces can be distributed over
30 a larger surface, as already illustrated in figure 3,
and the deformation of the optical element 2 as a
consequence of the spring forces is thereby minimized.
There is thus a uniform force distribution.

35 [0031] Figure 4 illustrates a possible variant of the
fitting of the holding elements 7 or of the fastening
elements 10 on the optical element 2. In accordance

with figures 1 and 2, the holding elements 7 or the
fastening elements 10 are fitted on the optical element
2 in such a way that the holding elements 7 or the
fastening elements 10 are fitted on the optical element
2 in a fashion perpendicular to the optical axis 6 of
the optical element 2, and precisely counteract a force
F_G' that, together with a force F_Z, produces the weight
force F_G. As previously, the force F_Z is compensated by
means of the connecting members 4 or is absorbed by
them. However, as illustrated in figure 4a, it is also
possible to fit the holding elements 7 or the fastening
elements 10 on the optical element 2 at a specific
angle α to an axis that is orthogonal to the optical
axis 6.

[0032] The force distribution is sketched in figure 4b
in a plan view onto the optical element 2, it also
being possible for the forces to be inclined to the
plane of the drawing.

[0033] The fitting of spring elements, specifically
the pneumatic spring elements 11, and their activation
are performed after the mounting and adjustment,
carried out in the usual way, of the optical element 2.
Owing to the soft spring elements 7 and 11, there are
no critical mounting tolerances for the fastening of
the spring elements 7 or 11 on the optical element 2.

[0034] A lateral displacement of the optical element 2
is virtually prevented by the device 1 in the
projection objective PL illustrated in figure 1, it
being impossible, however, to compensate tilting of the
optical axis 6 of the optical element 2 with the aid of
a device 1 according to figure 1.

[0035] Force should act on the holding elements 7 as
far as possible in such a way that it is also

impossible for the optical axis 6 of the optical
element 2 to be tilted in relation to a mount axis of
the mount 3.

5   [0036] Since the elasticity of the connecting members
4 can fluctuate owing to manufacturing tolerances or
else material inhomogeneities, it is possible for there
to be an impermissibly large tilting of the optical
element 2 in relation to the mount 3 despite the
10   correct design of the connecting members 4 against
tilting.

[0037] Likewise, a tilting moment or a torque occurs
when the force does not act on the holding elements or
15   spring elements 7 or the fastening element 10 at the
centroid 13 of the optical element.

[0038] Figures 5a and 5b illustrate a measure by means
of which it is possible to apply or displace the
20   resulting force of two spring elements 7 such that the
resulting force F_{res} acts at the centroid 13.

[0039] Two pairs of spring elements 7 are provided in
accordance with this exemplary embodiment, the optical
25   element 2 being respectively connected laterally to a
pair of spring elements 7. Each pair of spring elements
7 is prestressed by a distance s_0 such that the
resulting force F_{res} of the spring element pair 7, which
is transmitted to the optical element 2, can have its
30   magnitude set such that it compensates the weight force
of the optical element 2. If all the springs are
designed identically with reference to the spring
force, and the prestress applied is also equal, the
resulting force F_{res}, which acts at the centroid 13, is
35   half the weight force on each side of the optical
element 2. Consequently, the resulting force F_{res}' runs
respectively in the middle between the spring elements

7 on each side, as is illustrated by dashes. A tilting
moment or a torque would be produced if the centroid 13
is not located ideally on the action line of F_{res}' but,
as illustrated, is offset by a spacing e in the
direction of a spring element 7. In order to avoid
this, the action line of the resulting force F_{res}' must
be displaced to the centroid 13, where it then
counteracts the weight force F_G as F_{res} with the same
magnitude.

[0040] The displacement of the action lines of the
resulting force F_{res}' to the centroid 13 is achieved by
virtue of the fact that independently of the other
spring element 7 of a spring element pair one spring
element 7 of the spring element pair is more strongly
stressed by a stressing device 14 (shown only
schematically) as adjusting mechanism by the distance
Δs with the aid of a force, and the other spring
element 7 is relieved by a force of equal magnitude. It
is to be borne in mind here that F_{res} continues to
correspond in total from both sides to the weight force
F_G in order to achieve the desired compensation of the
weight force and - in accordance with this exemplary
embodiment - also to avoid tilting.

[0041] For a pair of spring elements 7 that is
prestressed by the distance s_0 and of which one spring
element 7 is now additionally stressed by the path Δs
while the other spring element 7 is relieved by the
distance Δs, the magnitude of the resulting force F_{res}
is yielded from the following equation, the spring
constant c for the spring elements 7 of a pair being
required to be of equal magnitude in each case:

$$F_{res} = c(s_0 + \Delta s) + c(s_0 - \Delta s) = 2cs_0.$$

[0042] The spacing e of the centroid 13 from F_{res}',
that is to say the central line between the two springs
is calculated using the following formula:

$$e = h \cdot \Delta s / s_0$$

h respectively being the spacing of a spring element 7
from the central line between the two spring elements
7.

[0043] In one design of the device 1 having the
adjusting mechanism illustrated in figures 5a and 5b,
the device 1 is therefore designed simultaneously as a
tilt and weight compensator in order thus to prevent
creeping and tilting of the optical element 2 during
installation and when being operated in the projection
objective PL.

We claim:

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Deletions	5
Moved from	0
Moved to	0
Style change	0
Format changed	0
Total changes	18

[0041] For a pair of spring elements 7 that is prestressed by the distance s_0 and of which one spring element 7 is now additionally stressed by the path Δs while the other spring element 7 is relieved by the distance Δs, the magnitude of the resulting force F_{res} is yielded from the following equation, the spring constant c for the spring elements 7 of a pair being required to be of equal magnitude in each case:

$$F_{res} = c(s_0 + \Delta s) + c(s_0 - \Delta s) = 2cs_0.$$

[0042] The spacing e of the centroid 13 from F_{res}', that is to say the central line between the two springs is calculated using the following formula:

$$e = h \cdot \Delta s / s_0$$

h respectively being the spacing of a spring element 7 from the central line between the two spring elements 7.

[0043] In one design of the device 1 having the adjusting mechanism illustrated in figures 5a and 5b, the device 1 is therefore designed simultaneously as a tilt and weight compensator in order thus to prevent creeping and tilting of the optical element 2 during installation and when being operated in the projection objective PL.

We claim: